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METAL SUBSTRATES WITH LASER-INDUCED MMC-COATING
[Metallsubstrate mit laserinduzierter MMC-Beschichtung]

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The present invention relates, on the one hand, to a material of aluminum or aluminum alloy with a wear-resistant and load-bearing MMC surface layer and its use in applications where wear and weight are critical and where high material strength is also required, and, on the other hand, a laser-induced method of manufacturing such MMC layers on aluminum or aluminum-alloy substrates and its use to produce MMC layers 200 μm to 3 mm thick. /2*

Here, MMC stands for the English abbreviation "Metal Matrix Composite" and means Metal Matrix Composite layer. In the present text, MMC will always refer to the composite layer on a substrate. The substrate itself can be made of aluminum, aluminum alloy, or Al-based alloys or it may be a composite material whose surface that is to be coated is made of one of the aforementioned aluminum-containing materials. In the further description below, the term "aluminum substrate" will always refer to all commercially available materials of pure aluminum or aluminum alloy.

Surface-coated aluminum substrates that are provided with a hard and abrasion-resistant MMC layer often reveal a high wear resistance and good antifriction properties and can be used wherever surface properties such as hardness, bearing capacity, or heat resistance must be improved over some or all of the surface.

Metal surfaces on moving parts which, for example, are in sliding contact with other, usually metallic, surfaces are generally subject

*Numbers in margin indicate pagination in foreign text.

to severe wear phenomena, particularly when aluminum materials are used. Consequently, such parts frequently require a wear-resistant coating. To a great extent, the wear depends on the mechanical properties of the microstructure of the materials in question. In general, high demands are placed on wear-resistant coatings, such as good bonding of the layer to the substrate, high compatibility of the individual components with respect to their thermomechanical properties (thermal expansion), and good heat conduction in both the substrate and the coating, particularly at the transition between the coating and the substrate. In order to assure a long lifetime of such materials, the solubility of the coating components in the substrate (diffusion) must generally be as low as possible, the thickness of the wear-resistant coating as great as possible (abrasion), and the hardness of the coating high (friction).

Aluminum substrates that are provided with an MMC layer combine properties such as high material strength, surface hardness, and load-bearing capacity of the corresponding MMC composite with the ductility and tenacity of the aluminum substrate. The resulting favorable relationship between rigidity and weight makes such materials of great interest for use in applications where weight is critical, in which good material properties are required, such as in aerospace or for highly accelerated components in vehicle manufacture and in the machine and textile industries.

It is known to include ceramic materials in aluminum alloys, their properties greatly improving elasticity and hardness and increasing the heat resistance and fatigue resistance of the materials significantly. Ceramic materials can be included in the surface of aluminum substrates by deposition of a ceramic-metal powder mixture on the substrate surface and then melting the metal powder and part of the substrate surface.

Thus, European Patent specification EP 0 221 276 describes a process for producing ceramic composites on the surface of aluminum alloy substrates by means of deposition of a corresponding powder mixture on the substrate surface and then melting the powder and a part of the substrate surface by means of laser beams, whereby melting the powder and substrate components forms an alloy which, upon cooling, produces a thin ceramic composite layer. This method of applying ceramic composite layers will be referred to as deposition coating below. The powder mixture used for this contains a powder of a metal carbide, such as titanium carbide, tantalum carbide, tungsten carbide, or molybdenum carbide, as well as a metal powder containing silicon and a metal that forms intermetallic compounds with silicon, such as copper, tantalum, tungsten, or molybdenum. Disadvantages of this method include, on the one hand, the choice of components of the powder mixture which, due to their differing coefficients of expansion, produce thermomechanical tension in the composite layer and, on the other hand, necessitate the addition of heavy elements to

compensate for the high density of the carbides and, thus, to avoid sedimentation of the carbides.

The publication "Laser Treatment Materials" (Pap. Eur. Conf.), Oberursel (DE), Ed. Bany L. Mordike, 1992, pp. 245-250 describes a deposition coating of this kind. To increase the surface hardness of AlSi alloys, ceramic particles such as SiC, TiC, B_4C, ZrO_2 are deposited on the corresponding surface and are worked into it by laser-induced melting of the surface layer, whereby the surface layer is melted ca. 3 mm deep. After solidification of the molten surface /3
region, there are essentially two regions: a central zone consisting of a mixture of ceramic particles and substrate material and an outer zone of quickly quenched AlSi. Since the process of mixing ceramic particles with the substrate material is limited in time to the molten state of this surface layer, this process leads to very nonhomogeneous surface layers with regard to the distribution of ceramic particles and, consequently-because of the different thermal expansion of the various zones-to the formation of microcracks in the surface layer.

The publication "Mémoires et études scientifiques de la revue de métallurgie", vol. 89, no. 11, November 1992, Paris, pp. 711-723 XP328376, K. Marcellou, et al., 'Traitement superficiel par laser de l'aliage d'aluminium 2024 par injection de poudre de SiC: étude microstructurale et comportement en usure-frottement' describes a coating method in which the surface undergoes laser-induced melting and SiC powder is introduced into the molten zone by means of a

carrier gas. Due to the strong reflection of aluminum surfaces, the substrate surface that is to be processed must first by roughened. The distribution of SiC particles is essentially determined by convection and diffusion processes in the laser-induced melting zone and, thus, it is difficult to control. Due to the temperature gradients in the melting zone resulting from the process, the MMC layers thus produced possess a structure with three different layers, with regard to their composition. In order to improve their homogeneity at least partially, layers produced in this way must be subjected to an additional thermal treatment for 15 to 20 minutes at 480 to 500°C.

A similar method of forming MMC layers by laser-induced melting of the substrate layer and simultaneous application of fine-grained SiC powder by means of a carrier gas is described in the publication "Key Engineering Materials", vols. 46, 47, 1990 CH, pp. 415-424, Riccardi, et al., 'Laser Assisted Formation of a Wear Resistant SiC-Metal Composite on the Surface of a Structural Aluminium Alloy.' The process-related problem of the high reflection of aluminum surfaces is overcome by deposition of a graphite layer. Moreover, on its way from the nozzle to the substrate surface, the SiC powder passes through the laser beam and, thus, is heated somewhat. Once again, however, the distribution of SiC particles in the surface layer is determined only by convection and diffusion whereby, in addition to the material properties, these processes are influenced substantially by the temperature gradients that are formed in the melting zone.

In addition to the nonhomogeneous distribution of the SiC particles that are added to the substrate surface, MMC layers produced by the above-mentioned method frequently have needle-shaped SiC crystals which cause nonhomogeneous properties in the MMC layer.

In general, the following problems arise from laser-induced melting of a powder mixture containing ceramic particles and its alloying with the surface of aluminum substrates:

- Due to the relatively brief laser-induced melting, there is frequently poor mixing of the alloy components, particularly when the powder mixture consists of several alloy elements with very different melting points.
- In many cases, the ceramic particles possess poor wettability with respect to the other alloy components, which can result in a nonhomogeneous particle distribution.
- Due to the differing specific gravity values of the ceramic particles and the other alloy components present in the melting zone, a time- and temperature-dependent separation takes place, which can result in an accumulation of ceramic particles at the bottom or on the surface of the melting zone.
- If the ceramic particles contain metal oxides such as Al_2O_3 or SiO_2 or metal nitrides such as Si_3N_4 or AlN, part of the ceramic particles can decompose in the melting zone during the alloying process. Ceramic particles that contain metal oxides tend to break down to form oxygen and ceramic particles that

contain metal nitrides break down to form nitrogen. Since these gases have no time to escape the melt, due to the short melting processes, undesirable gas inclusions often form, which together with the broken down ceramic particles form nonhomogeneous and mechanically unstable composite layers.

- The CO_2 laser commonly used for the laser-induced melting emits electromagnetic radiation in the infrared region with a typical wavelength of the most energy-rich radiation of 10.6 μm. Since electromagnetic radiation of this wavelength is only weakly absorbed by aluminum substrates, the alloying of the substrate in this way is difficult to implement and normally results in low thicknesses of the composite layer. With deposition coating the process of heating the substrate surface occurs primarily by melting of the powder mixture and subsequent conduction of heat to the substrate surface. Depending on the size and temperature of the melting zone, the time- and temperature-dependent decomposition rate of the ceramic particles can be correspondingly high. Moreover, it is difficult to control the alloy quality.

The object of the present invention is to provide a material /4 of aluminum or aluminum alloys with an MMC surface whose MMC layer is wear-resistant, i.e., hard, abrasion-resistant, and pore-free and that, by using the proper MMC layer thickness, distributes local

incident forces over a larger surface of the substrate (Herz pressure), thus giving the MMC layer a load-bearing character.

An additional object of the present invention is indicate a method for the reproducible production of materials with a wear-resistant and load-bearing MMC surface that overcomes the problems mentioned above with regard to an MMC layer on an aluminum substrate.

The object is achieved in accordance with this invention in that the MMC layer contains homogeneously distributed SiC particles in an AlSi matrix, which is hypereutectoid with respect to the Si content, with primary Si crystals and the MMC layer has a thickness of 200 μm to 3 mm.

The material in accordance with this invention is based on an aluminum substrate with a wear-resistant and load-bearing MMC surface, whereby the substrate consists of aluminum or an aluminum alloy, the purity and composition of which is noncritical. In practice, aluminum with a purity, for example, of 98.3% or greater or aluminum-based alloys with and without dispersion hardening and Al composites have proven valuable. Cast, rolled, wrought, and forged alloys of aluminum are preferred.

Examples of preferred substrate materials are the molded alloy CEN 7149, the cast alloy CEN 44400 and the rolled alloy CEN 42100, whose composition in wt-% of the elements in question are presented in Table 1.

Table 1: Composition of preferred substrate materials in wt-% of the elements in question.

	Al	Zn	Mg	Cu	Zr	Mn	F	Si	Cr	Ti
CEN 7149	Bal.	6.9	2.7	1.8	0.18	0.18	0.09	0.08	0.02	0.01
CEN 44400	Bal.	0.1	0.1	0.03	-	0.3-0.4	0.4	7	-	0.05
CEN 42100	Bal.	0.07	0.25-0.4	0.03	-	0.05	0.15	6.7-7.5	-	0.06-0.12

The substrate materials can be produced, for example, by casting, extrusion, extrusion molding, or rolling.

The MMC layer of the material made in accordance with this invention preferably has a layer thickness of 1 to 1.8 mm. The grain size of the silicon carbide (SiC) particles included in the AlSi matrix may be, for example, between 5 µm and 100 µm. The Si primary crystals in the AlSi matrix typically have a grain size of 5 µm and 50 µm. The AlSi matrix is an alloy of aluminum (Al) and silicon (Si), whereby the Si portion lies, for example, between 20 wt-% and 50 wt-%. The amount of SiC ceramic particles in the AlSi matrix is generally in the range of 1 to 40 wt-%.

The lifetime of the material, i.e., the possible time during which the material can be used and the same physical and chemical properties are retained, is highly dependent on the technical load on the material. For such a material to have a long lifetime, the heat formed during usage, mostly on the surface of the material, must be

rapidly eliminated. With the material made in accordance with this invention, this is accomplished, in particular, by a high thermal conductivity, which is achieved by the combination of thermal conductivities of the Al-rich matrix, with a thermal conductivity between 100 and 200 W/mK and of the SiC particles, with a thermal conductivity between 40 and 100 W/mK.

A high degree of adhesion between the MMC layer and the substrate is crucial to the lifetime of the material. Equally important, however, with respect to the thermomechanical load (crack formation) of the material is the coefficient of linear expansion of the MMC layer which, depending on the layer composition, may be between $9*10^{-6}$ 1/K and $20*10^{-6}$ 1/K.

Another important property for the wear resistance of the material made in accordance with this invention is the porosity of the MMC layer which should be, for example, less than 5%. Thus, the amount of aluminum carbide (Al_4C_3) in the MMC layer should be less than 1 wt-%. Al_4C_3 components can worsen the mechanical wear-related properties of the MMC layer and can also be sensitive to moisture, releasing aluminum hydroxide. /5

The good homogeneity of an MMC layer made in accordance with this invention on a substrate of CEN 42100 can be seen, for example, in Fig. 1.

Figure 1 shows a metallurgical micrograph of a typical MMC layer, which contains 40% SiC in an AlSi40 matrix. The designation AlSi40

indicates an AlSi matrix with 40 wt-% Si. The micrograph clearly shows the black SiC particles and the gray Si crystals in the AlSi matrix. The relative grain sizes of the individual components of the wear-resistant composite layer and their spatial distribution may also be seen.

Due to its high wear resistance and good antifriction properties, the material made in accordance with this invention can be used for highly stressed parts in vehicles and machines, such as pumps, or in spark-ignition or compression-ignition engines for tappets, pistons, and valve seats, or in gearboxes for selector forks. Other important applications of the material made in accordance with this invention include structural components with surfaces affected by friction and abrasion, such as brake linings on disk and drum brakes.

Because of its high strength and rigidity combined with low weight, compared to other materials, the material made in accordance with this invention also has many possible applications where weight is critical, such as in aerospace or for highly accelerated components in automotive engineering, and in the machine and textile industries.

In this method, the object established above is achieved in that either a powder mixture containing Si powder, SiC particles and prealloyed AlSi powder or a powder mixture containing Si and Al powder as well as SiC particles is directed by means of a stream of inert carrier gas through a nozzle that is aimed at the substrate surface and on its path between the nozzle opening and the substrate surface

the powder mixture passes through a laser beam to be heated, whereby the laser beam is aimed at the impact surface of the powder mixture on the substrate surface and the powder mixture is heated by passing through the laser beam and by the heat radiated from the melting zone present on the substrate surface to the extent that a considerable portion of the heat required for producing a homogeneous alloy from the powder mixture is produced by the powder mixture that impinges on the substrate surface and a melting zone, which is essentially limited by the laser beam and the beam of powder mixture, forms on the substrate surface, said melting zone containing the powder mixture and a small amount of molten substrate material, and an MMC layer is formed in certain areas by a predetermined relative motion between the substrate being coated and the impingement surface of the powder mixture or the laser beam.

Thus, the material made in accordance with this invention can be produced by a laser-induced powder-coating process. The method of producing MMC layers in accordance with this invention involves deposition of a powder mixture by means of an inert carrier gas, whereby the carrier gas containing the powder mixture flows through a nozzle that is aimed at the substrate surface and the powder mixture passes through a laser beam on its way to the substrate surface.

The powder mixture used in the method of this invention contains, in addition to the SiC ceramic particles, either Si and prealloyed AlSi powder particles or Al and Si powder particles.

Preferred in the former case are prealloyed AlSi12 particles with a grain size of 45 to 105 µm. A silicon powder with a typical grain size of 20 to 100 µm is preferred. Also preferred is coarse-grained SiC with a grain size between 45 and 100 µm or fine-grained SiC with grain sizes of 5 to 45 µm. The designation AlSi12 refers to an AlSi matrix with 12 wt-% Si. The percentage of AlSi12 particles in the entire powder mixture may be, for example, between 28 and 90 wt-%, that of the Si powder, for example, between 5 and 43 wt-%, and that of the SiC particles, for example, between 1 and 50 wt-%.

In the latter case, i.e. when a powder mixture is used that contains Al and Si powder in addition to SiC particles, Si powder with a grain size of 20 to 45 µm is preferred. SiC with a grain size of 5 to 100 µm is preferred. Also preferred is Al powder with a grain size of 5 to 100 µm. Suitable percentages of Al powder with reference to the entire powder mixture are between 25 and 80 wt-%, those of the Si powder between 10 and 50 wt-%, and those of the SiC particles between 1 and 50 wt-%.

The powder mixture absorbs enough energy from passing through the laser beam and from the radiated heat of the melting zone on the substrate surface that a significant portion of the heat required to produce a homogeneous alloy from the powder mixture is provided by the powder mixture that impinges on the substrate surface. The laser beam is directed at the substrate surface in such a way that it essentially

illuminates the substrate surface on which the powder mixture impinges. From the heat energy directly transferred by the laser beam onto the substrate surface and the heat energy transferred by the powder mixture, part of the substrate surface is melted and a melting zone, containing the powder mixture and a small amount of molten substrate material, is formed that is essentially limited by the laser beam and the beam of powder mixture. Since, due to the brief process times that are selected, only a small layer thickness of the substrate surface is melted, the material composition of the melting zone is determined primarily by the composition of the powder mixture. An MMC layer is formed in certain areas, for example, by predetermined relative motion between the substrate being coated and the impingement area of the powder mixture or laser beam. This relative motion can be achieved either by partial or complete coating of the substrate surface with the laser and powder mixture beam and/or by selective movement of the substrate with respect to a laser and powder-mixture beam that is constant in place and time. Thus, a time- and location-dependent local melting zone is formed on each part of the substrate surface, where the desired MMC alloy is formed. /6

One main problem in MMC production by means of a liquid phase, as occurs in the melting zone, is the wettability and the reactivity of the ceramic particles or ceramic fibers with the molten metal. The production of SiC-containing MMC layers often fails due to the poor wettability of SiC ceramic particles by the alloy melt. Wettability

can be improved by adding certain alloy elements, such as magnesium, and by using higher process temperatures.

An additional difficulty is the reactivity of SiC, which is thermodynamically unstable with respect to an aluminum melt and can enter into the following chemical reaction:

(1) $Al + SiC \rightarrow Al_4C_3 + Si$

The resulting Al_4C_3 worsens the mechanical properties of the MMC. Moreover, the aluminum carbide reacts sensitively to moisture, releasing aluminum hydroxide. The temperature-dependent formation of aluminum carbide can be reduced by the introduction of Si to the Al.

In order to keep the formation of Al_4C_3 as low as possible during the alloying process, it was found advantageous to work with a hypereutectic amount of Si, which is greater than 12 wt-% and preferably greater than 20 wt-%.

Due to the rapid solidification in the laser process, the Si primary crystals remain in the range of less than 50 μm, for example.

The reactivity and wettability are two problems that are linked together and are highly dependent on the duration of the reaction between the ceramic particles and the aluminum alloy melt, the temperature, and the composition of the alloy. In the system examined here, high temperatures of greater than 1,600 C promote wettability. The formation of Al_4C_3 in accordance with equation (1) on the SiC-Al interface is suppressed by the high·Si content.

The use of a laser is ideal for producing SiC-containing MMC layers on an aluminum substrate, since very high temperatures can be achieved in the metal melt for a brief period of time. Due to the very rapid heating of the alloy powder and the limited extent of the molten bath, on the one hand, and the high heat capacity relative to the molten bath, on the other, the melt is quickly cooled, so that the duration of the molten state is extremely short, i.e., on the order of 0.05 to 0.5 s. Due to the rapid cooling of the melting zone, the duration of the molten state essentially corresponds to the time of interaction between the laser beam and the substrate surface.

In order to achieve the power density required for the heating process, solid-state or molecular lasers, in particular, can be used as power sources. Particularly suitable are solid-state lasers, such as the neodymium:YAG laser or molecular lasers, such as the CO_2 laser.

The most important molecular laser for material treatment is the CO_2-laser, which has over 100 wavelengths in the range of 9.14 μm to 11.01 μm with a maximum intensity at 10.6 μm. It is characterized by a high degree of efficiency and a high output power in continuous operation. The efficiency achievable in practice, η, is on the order of $\eta \approx 0.3$. Depending on the laser design, typical radiated power in continuous operation of up to 25 kW is achieved.

When a CO_2 laser is used in the method of the present invention, the power density is dependent on optimizing the remaining process

parameters. With interaction times defined as the ratio of the beam diameter to the raster rate, the power density is suitably between 100 and 1,500 W/mm, preferably between 300 and 700 W/mm^2.

The most important solid-state laser for technical applications is the Nd (neodymium):YAG laser. YAG is the abbreviation for yttrium-aluminum-garnet ($Y_3Al_5O_{12}$). The most powerful laser transition of a Nd:YAG laser occurs at a wavelength of $\lambda = 1.064\ \mu m$. One significant advantage of Nd:YAG lasers over CO_2 lasers is the possibility, due to the shorter wavelength, of guiding the beam of the YAG laser through /7 glass fibers and the better absorption when treating aluminum substrates.

The principle of the laser-induced powder coating process in accordance with this invention for manufacturing SiC-containing MMC layers **6** on aluminum substrates **3** is presented, for example, in figure 2. The powder mixture **1**, which consists of a powder of prealloyed Al-Si alloy, Si powder, and SiC particle, is applied by means of a stream of inert gas, such as helium (He), argon (Ar), Nitrogen (N_2), or carbon dioxide (CO_2), which moves the powder mixture through a nozzle **2** onto the surface of substrate **3**. Part of the flight path of the powder mixture passes through laser beam **4**, in which the powder mixture, particularly the SiC particles, absorbs much heat, some of which is imparted to the surface of substrate **3** upon impact. Laser beam **4** is arranged such that, first of all, it passes through the

flight path of the powder mixture and, secondly, it heats the point of impact **5** of the powder mixture on the substrate surface.

Since the powder mixture is moved by an inert-gas stream on its flight from the nozzle to the substrate surface, this inhibits oxidation of the powder particles during heating in the laser beam and it creates an inert atmosphere at the point of impact of the powder on the substrate surface, thereby protecting the melting zone on the substrate surface from oxygen.

Due to the brief processing times, the loss of alloy elements to evaporation is negligible. The deposition parameters are also selected such that the substrate surface is melted only to a depth of several micrometers, i.e., between, for example, 10 and 150 µm, and particularly less than 60 µm, so that the material composition of the MMC layer essentially coincides with that of the powder mixture. This process makes it possible to produce MMC layers with very low porosity, less than 5%, and with excellent adhesion to the substrate.

For the laser-induced powder coating process, aluminum and silicon powder can also be used instead of prealloyed AlSi powder in the desired composition.

A maximally high alloying temperature assures low viscosity in the melt and, thus, optimal mixing due to Maranghoni convection, resulting in a high degree of homogeneity in the resulting MMC layer.

Activity related to the invention revealed that the heat absorption by the powder components occurred primarily on the way

through the laser beam during their flight from the nozzle to the substrate surface and, in addition to the power of the laser beam, it essentially depends on the absorption properties and residence time of the particles in the laser beam and on their mass, heat capacity, and mean diameter. A simplified mathematical description of the mean temperature change of a powder particle on its flight through the laser beam can be obtained from equation (2). This description does not take into account a possible phase change by the particle when heated, e.g. a phase transition from solid to liquid.

$$(2) \qquad \Delta T = [A \cdot p \cdot t_p \cdot \Pi \cdot R_p{}^2] \cdot \left[\frac{1}{m \cdot C_p}\right]$$

A: Absorption coefficient
p: Power density of laser [W/m^2
t_p: Residence time of particle in laser beam [s]
R_p: Mean radius of particle [m]
m: Mass of particle
C_p: Heat capacity of particle

Assuming a typical residence time of the particle in the laser beam of $t_p = 6\text{-}10^{-4}$ s and a CO2-laser power density of $p = 4.55\text{-}10^8$ W/m, equation (2) was used to calculate the mean temperature change of the powder particles used in the method of this invention. The results of these calculations and the particle-specific material values such as absorption coefficient, mean particle diameter, heat capacity, and density are presented in Table 2.

Table 2. /8

Approximate, calculated temperature increase, □T, of the powder particles used in the method of this invention during heating in the laser beam, whereby a power density of the CO2 laser of $p = 4.55 \cdot 10^8$ W/m^2, assuming a residence time of the particles in the laser beam of $t_p=8 \cdot 10^{-4}$s.

	Units	AlSi12	Si	SiC
A	[-]	0.1	0.2	0.5
Rp	[m]	25e-6	25e-6	25e-6
Cp	[J/kg·K]	900	700	670
ρ	[kg/m3]	2.65e3	2.33e3	3.15e3
ΔT	[K]	336	983	1900

It may be seen from Table 2 that, of the material-specific parameters, the absorption coefficient, A, exerts the greatest influence on the heat absorption of the particles. The absorption coefficient, A, is dependent on several parameters, such as the temperature, T, and the condition of the particle surface (roughness, oxidation layer). The absorption coefficients, A, listed in Table 2 are approximate values that provide some indication of the order of magnitude of the influence on the heat absorption of individual particles.

Based on pyrometric temperature measurements, the surface temperature of the melt during deposition of the powder mixture of AlSi12, Si, and SiC may be, for example, in the range of 1,800 to 2,100°C. If the corresponding powder mixture without SiC is deposited,

on the other hand, the temperature in the melting zone is only in the range, for example, of 1,300 to 1500°C. This fact points to a certain influence of SiC particles on the temperature of the melting zone. Due to the high impact velocity of the SiC particles, typically 1 to 4 m/s, on the surface of the melting zone, their high kinetic energy is readily able to overcome the surface tension of the melt, so that they are immediately absorbed in the melting zone. Thanks to the good heat conduction between the SiC particles and the AlSi melt, the ceramic particles are easily able to give up their heat energy to the melt.

Although temperatures as high as possible are desired in the melting zone for the method of this invention, the maximum possible melt temperature is 2,400°C and it is limited by the vapor pressure of aluminum and the decomposition of SiC.

As seen in Table 2, the components used in accordance with the method of this invention have similar densities, ρ, thus insuring that no separation of the individual components occurs in the melting phase.

As stated above, with their high heat absorption the SiC particles favor the metallurgical coating process. The use of SiC also makes it possible to produce laser-induced MMC layers with relatively low thermomechanical residual stress values, since the SiC particles possess a much lower coefficient of thermal expansion than the AlSi matrix. Thermomechanical residual stress arises during cooling, due to the different expansion conditions of the layer and the substrate and

due to the temperature gradient between the melting zone and the substrate. Moreover, the process parameters of the coating process influence the formation of thermomechanical residual stress. Due to the small surface of the melting zone compared to the high heat capacity of the substrate and its high temperature gradient during the process, the melt cools very quickly, so that the thermomechanical residual stress cannot build up during the coating process. Such mechanical residual stresses that remain or are frozen in the material can lead to crack formation in the layer and to fatigue phenomena in the material, thereby possibly reducing its lifetime.

The mechanical properties of the MMC layer, such as modulus of elasticity, hardness, and thermal and fatigue strength, can be improved by using small quantities of alloying additives, such as titanium, manganese, iron, cobalt, nickel, copper, magnesium, or zinc. Within a certain range, the thermomechanical residual stresses in the /9
MMC layer can be reduced by alloying additives with low coefficients of thermal expansion. Typical quantities of alloy additives for improving the mechanical properties and, possibly, the further workability, with reference to the alloy composition, are Cu 0.1-5 wt-%, Zn 0.1-7 wt-%, Mg 0.1-6 wt-%, Ti 0.1-1 wt-% and Fe and Ni 0.1-1.5 wt-%.

As seen in Table 3, Si and SiC have low coefficients of thermal expansion, compared to that of aluminum. In addition, the coefficients of expansion of AlSi40 + 20% SiC and AlSi40 + 40% SiC show that adding

Si or SiC to the alloy reduces the overall thermal expansion of the MMC layer.

Table 3: Mean thermal coefficient of expansion of the materials used in the method of this invention.

	Coefficient of thermal expansion [-]
Al	23e-6
Si	7.6e-6
SiC	2.4e-6
AlSi40 + 20% SiC	14.2e-6 *
AlSi40 + 40% SiC	11.5e-6 *

*) calculated by the mixing rule.

The laser-induced production of SiC-containing MMC layers in accordance with this method of this invention permits very high alloying temperature and favors the wettability of the SiC particles in the melt.

The brief alloying times made possible by the method of this invention and the optimal alloy compositions that have been determined prevent the formation of undesirable Al_4C_3 and alloy the production of homogeneous, pore-free MMC layers with ideal metallurgical process parameters.

The good thermal coupling between the laser beam and the SiC particles also makes it possible to produce MMC layers with a large bearing layer thickness. Adding the ceramic SiC particles to the MMC

alloy also lowers the coefficient of thermal expansion of the resulting MMC layer, thereby reducing the danger of crack formation due to thermomechanical stress.

Claims

1. A material consisting of aluminum or aluminum alloys with a wear-resistant and load-bearing MMC surface layer,

characterized in that

the MMC layer contains homogeneously distributed SiC particles in an AlSi matrix, which is hypereutectoid with respect to the Si content, with primary Si crystals and the MMC layer has a thickness of 200 µm to 3 mm.

2. A material as recited in Claim 1, characterized in that the SiC particles possess a grain size between 5 µm and 100 µm.

3. A material as recited in Claim 1, characterized in that the Si crystals in the AlSi matrix possess a grain size between 5 µm and 50 µm.

4. A material as recited in Claim 1, characterized in that the AlSi matrix contains Si in an amount of 20 to 50 wt-%.

5. A material as recited in Claim 1, characterized in that the /10 AlSi matrix contains 1 to 40 wt-% SiC as homogeneously distributed SiC particles.

6. A material as recited in Claim 1, characterized in that the MMC layer contains less than 1 wt-% Al_4C_3.

7. Use of the material as recited in Claims 1 through 6 for applications where wear and weight are critical and that also require high material strength.

8. A method of laser-induced production of wear-resistant and load-bearing MMC layers on substrates of aluminum or aluminum alloys, characterized in that

either a powder mixture containing Si powder, SiC particles and prealloyed AlSi powder or a powder mixture containing Si and Al powder as well as SiC particles is directed by means of a stream of inert carrier gas through a nozzle that is aimed at the substrate surface and on its path between the nozzle opening and the substrate surface the powder mixture passes through a laser beam to be heated, whereby the laser beam is aimed at the impact surface of the powder mixture on the substrate surface and the powder mixture is heated by passing through the laser beam and by the heat radiated from the melting zone present on the substrate surface to the extent that a considerable portion of the heat required for producing a homogeneous alloy from the powder mixture is produced by the powder mixture that impinges on the substrate surface and a melting zone, which is essentially limited by the laser beam and the beam of powder mixture, forms on the substrate surface, said melting zone containing the powder mixture and a small amount of molten substrate material, and an MMC layer is

formed in certain areas by a predetermined relative motion between the substrate being coated and the impingement surface of the powder mixture or the laser beam.

9. A method as recited in Claim 8, characterized in that the composition of the powder mixture contains between 28 and 90 wt-% prealloyed AlSi12, between 5 and 43 wt-% Si, and between 1 and 50 wt-% SiC.

10. A method as recited in Claim 8, characterized in that the composition of the powder mixture contains between 25 and 80 wt-% Al, between 10 and 50 wt-% Si, and between 1 and 50 wt-% SiC.

11. A method as recited in Claim 8, characterized in that the temperature of the melting zone during the alloying process is between 1,300 and 2,100°C.

12. A method as recited in Claim 8, characterized in that, during the alloying process, the substrate surface is melted to a depth of between 10 and 150 μm, preferably less than 60 μm.

13. A method as recited in Claim 8, characterized in that the particles of the powder mixture strike the substrate surface at a velocity of 1 to 4 m/s.

14. A method as recited in Claim 8, characterized in that the duration of the liquid alloy state is locally less than 0.5 s.

15. A method as recited in Claim 8, characterized in that alloying additives, preferably Ti, Mn, Fe, Co, Ni, Cu, Mg, or Zn, are added to the powder mixture.

16. Use of the method as recited in Claim 8 for producing wear-resistant and load-bearing MMC layers with a thickness of 200 μm to 3 mm on substrates of aluminum or a aluminum alloys.

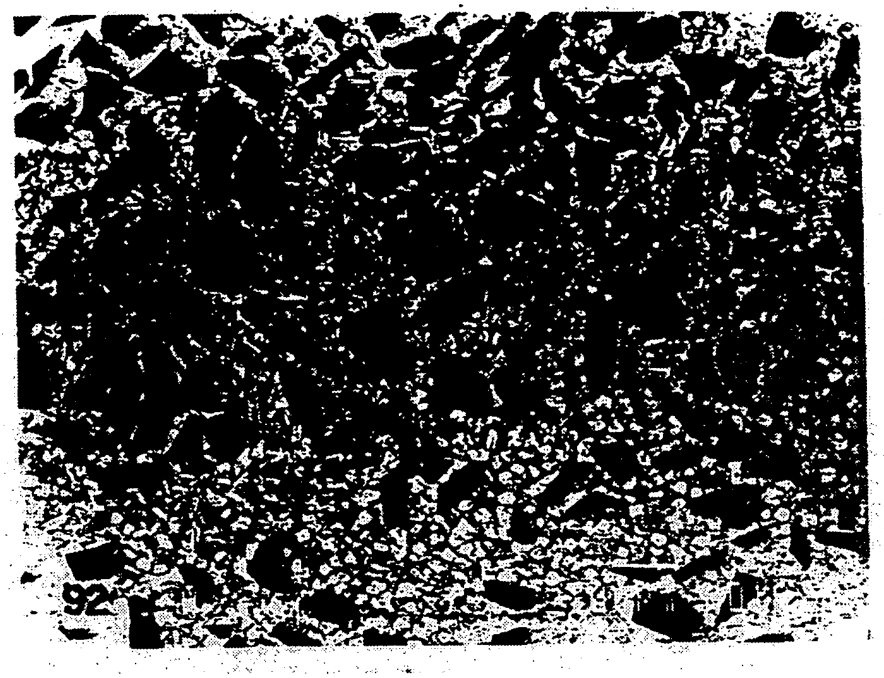

Figure 1: Metallurgical micrograph of an MMC layer on CEN 42100 with 40% SiC in an AlSi40 matrix.

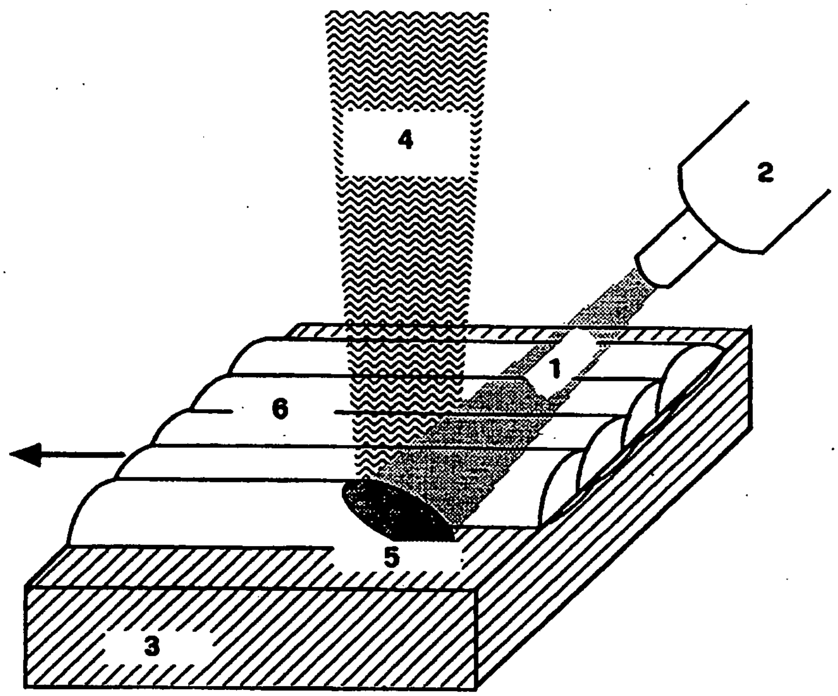

Figure 2: Principle of the laser-induced powder-coating method in accordance with this invention.